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THE PERFORMANCE OF PRIMATES FOLLOWING EXPOSURE TO PULSED WHOLE-BODY GAMMA-NEUTRON RADIATION

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FOREWORD
(Nontechnical summary)

The purpose of this paper is to consolidate the behavioral data from a number of studies conducted at the Armed Forces Radiobiology Research Institute concerning the performance capability of primates (Macaca mulatta) following exposure to high dose radiation. The animals used in these studies were all trained to the same shock motivated visual discrimination task and were exposed to a single whole-body pulsed (50-millisecond) dose of gamma-neutron radiation from a TRIGA Mark-F reactor. From these studies, performance data following exposures of 1100, 1700, 2600, 4900, 8900 or 15,200 rads are presented.

ABSTRACT

Eighty-eight monkeys (Macaca mulatta) were trained to perform a shock motivated visual discrimination task and were exposed to a single supralethal dose of pulsed gamma-neutron radiation. The postirradiation performance of these animals is presented in a manner which facilitates group comparisons of performance following doses of approximately 1100, 1700, 2600, 4900, 8900 or 15,200 rads. At these dose levels, group performance declined within minutes after exposure. For some subjects, the decline was so severe that the animals appeared comatose. The frequency with which a behavioral decrement was observed and the severity of the initial decrement appeared to be dose dependent. After the initial decrement, most animals at least partially regained their ability to perform the discrimination task. Performance was generally maintained at recovery levels until shortly before death. Factors which appeared capable of modifying observed postirradiation behavior include the gamma-neutron ratio of the radiation source and the nature of the behavioral task employed.

I. INTRODUCTION

The performance of subhuman primates following exposure to supralethal doses of radiation has been a primary radiobiology research interest of the armed services for a number of years. During this period of time, studies[1-11,13-30] have been conducted dealing with a variety of performance criteria following an equally varied array of radiation exposures. Most of these studies have appeared exclusively as scientific reports from military laboratories and have received limited distribution.

To date the various studies have not been consolidated into a composite report. The differences in the behavioral paradigms and radiation sources used to produce these data were sufficiently large and poorly understood to preclude such consolidation. Thesc difficulties remain. However, the data from a relatively large test sample of monkeys trained to a common behavioral task and exposed in a TRIGA Mark-F reactor at AFRRI are now available. The purpose of this report is to assemble these AFRRI data and to identify areas of further research.

II. MATERIALS AND METHODS

Eighty-eight monkeys (Macaca mulatta) weighing between 2.4 and 5.3 kg and ranging in age from 15 to 51 months were used in these studies. They were maintained in primate restraint chairs designed for behavioral studies and housed in individual isolation booths (Figure 1). Each animal was placed in the restraint chair at the beginning of training and was maintained in the chair until postirradiation testing was completed, approximately 25 days.

Figure 1. Chair and console in isolation cubicle

The animals were trained to a discrimination task consisting of a circle and a square simultaneously projected onto the backs of two transparent pressplates. An additional cue was also available to the animal; at the beginning of each trial a 15-watt house light was illuminated in the cubicle. An interval of 10 seconds elapsed between the onset of successive trials. After the onset of the visual stimuli, an animal was allowed 5 seconds to complete the problem by pressing the pressplate illuminated with a square. If he performed correctly, the house light extinguished and the subject remained in darkness for the remainder of the 10-second interval. If the subject performed incorrectly by pressing the circle or failed to respond within 5 seconds, a tonc was sounded, the cubicle light remained on, and an electrical shock was delivered to the subject.

The animals were trained to an accuracy criterion of 90 percent correct or better. On completion of training, each animal was subjected to a base-line test. The data from this test allowed each animal to serve as its own control.

Within 2 - 6 days following the base-line test, the animals were transported to an exposure room of the AFRRI-TRIGA reactor. They were positioned in the exposure room where previous dose mapping indicated that they would receive a predetermined dose of radiation. The actual exposure determinations were obtained by measuring the tissue kerma, free-in-air, and multiplying this value by an experimentally derived factor of approximately 0.83 to obtain the midline tissue dose (MTD).[12]

In all cases, behavioral testing began prior to irradiation and all animals were performing the task at criterion levels at the time of exposure. The animals were tested continuously for 2 hours postirradiation in the exposure room and were then returned to the laboratory environment.* Testing in the laboratory was conducted for 20-minute periods separated by intervals of 40 minutes from the 3rd through the 8th hour postirradiation. Beyond the 8th hour, 20-minute testing periods were separated by an interval of 100 minutes.

III. RESULTS

The mean midline tissue doses were approximately 1100, 1700, 2600, 4900, 8900, and 15,200 rads. The individual doses actually received, the percent correct responses, and response latencies for each animal are given in Appendix A, Tables A-1 through A-3. The behavioral data for the several exposure groups through 2 hours postirradiation are

* A number of animals were exposed to a second radiation dose and in these cases the animals were maintained in the exposure room of the reactor. None of the behavioral data following the second exposure is included in this report.

presented in Figures 2 - 7. For each dose, the data are presented in two graphs. In graph A, the cumulative percent of the sample performing the assigned task within each of four accuracy ranges (0-49, 50-74, 75-89, 90-100 percent) is presented. The mean correct response and mean latency of response (time from stimulus presentation to response) for blocks of 50 trials are presented in graph B. The mean preirradiation latency for the animals used in this study was approximately 1.1 seconds.

In the cumulative percent graphs, the proportion of animals in each range is based on the mean performance accuracy of individual animals in 10-minute blocks of

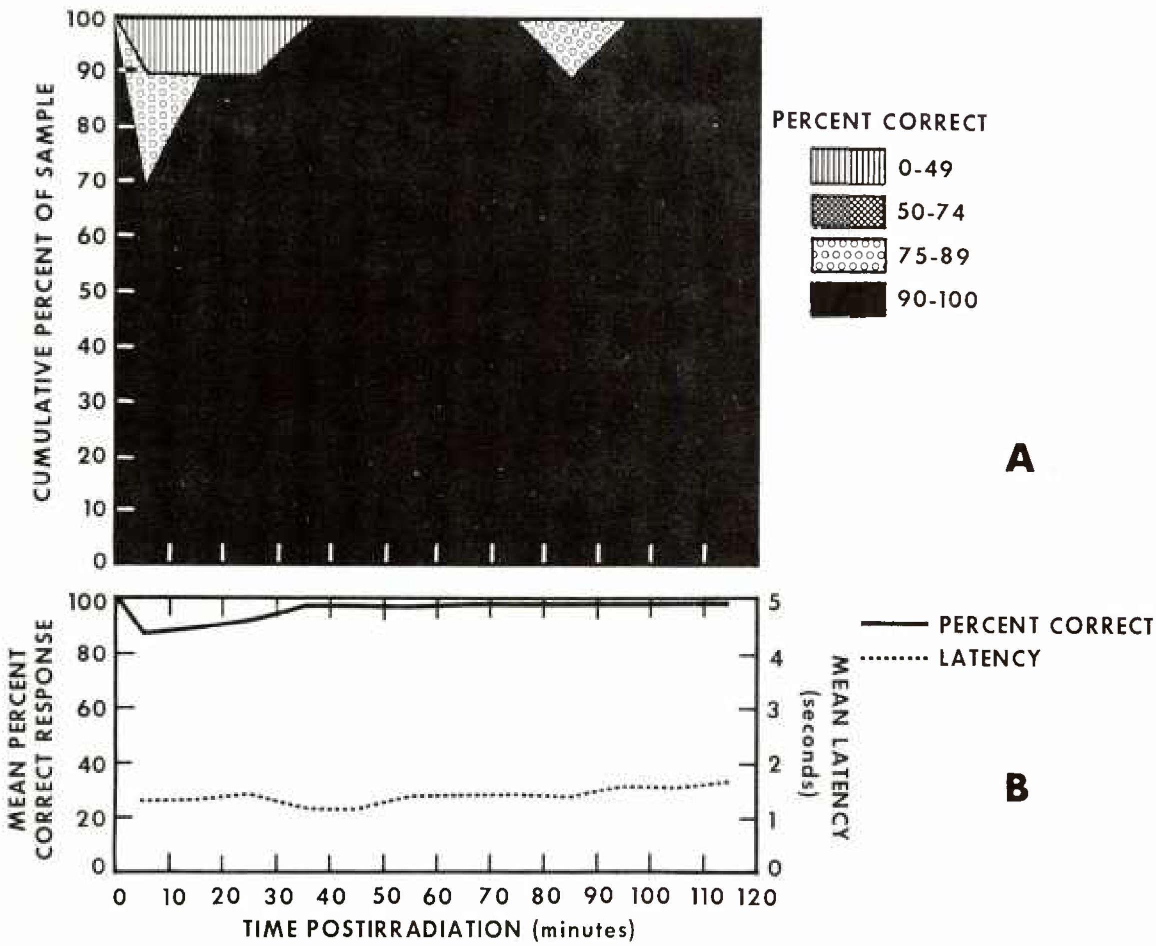

Figure 2. Behavioral data for animals (10) exposed to 1100 rads (midline tissue dose) of mixed gamma-neutron radiation

testing (50 trials). Thus, the reader may determine the percent of the population performing within any given accuracy limits for any time within the first 2 hours after exposure. For example, in Figure 2A, the solid black area at 10 minutes postirradiation includes 70 percent of the sample, indicating that 70 percent of the animals were performing with a mean accuracy between 90-100 percent correct for that 10-minute interval. Likewise, it can be determined that approximately 20 percent of the animals were performing the assigned task with an accuracy of greater than 75 percent correct and less than 90 percent correct during the same period. Combining ranges, it can

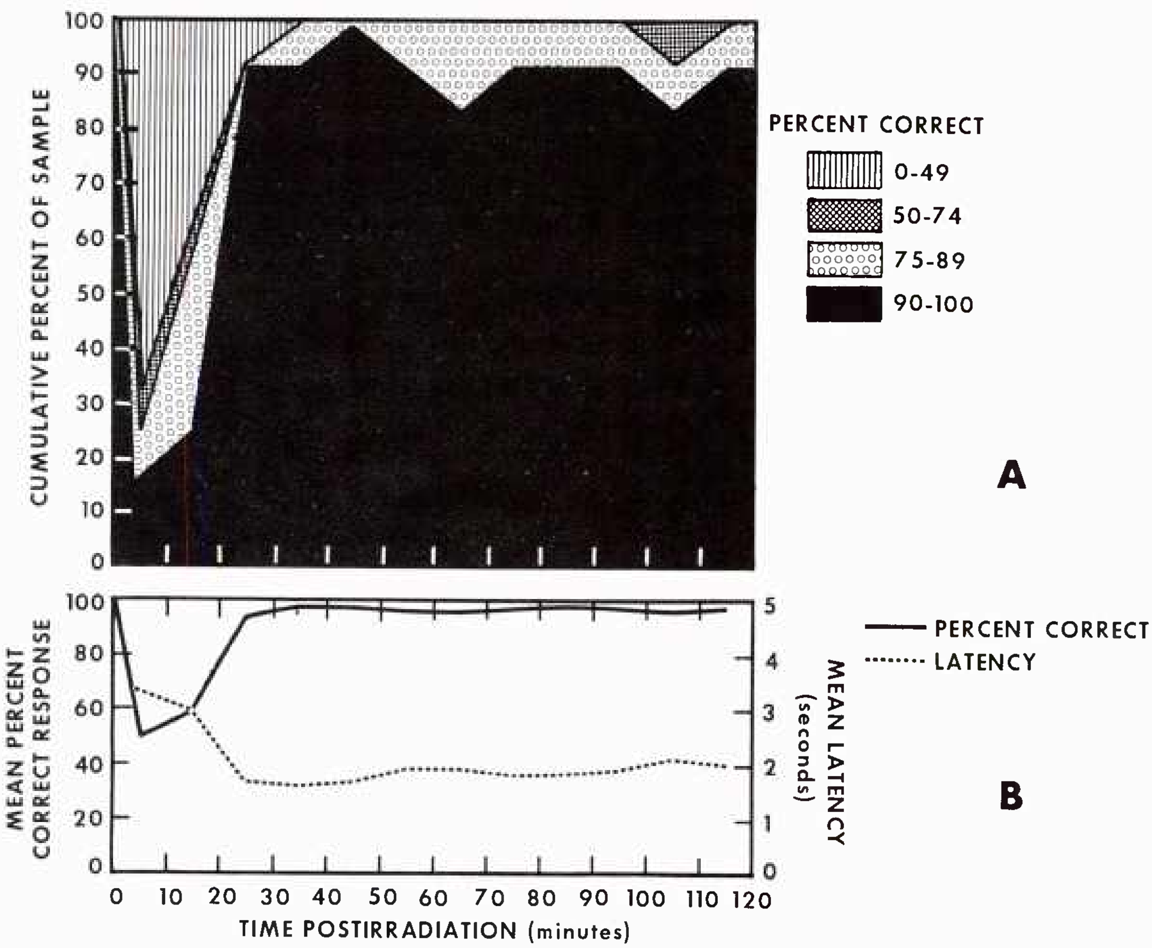

Figure 3. Behavioral data for animals (12) exposed to 1700 rads (midline tissue dose) of mixed gamma-neutron radiation

also be seen that 30 percent of the animals were performing at levels below 90 percent correct.

In the graphs of mean correct responses and mean latency of response, animals are excluded from the original test sample for computation purposes at the time of death. For example, the original sample size in Figure 6B (8900 rads) included five animals. This number was periodically reduced so that by 90 minutes after exposure the performance data are a function of only two surviving animals. A star appears on each graph as animals were eliminated from the sample.

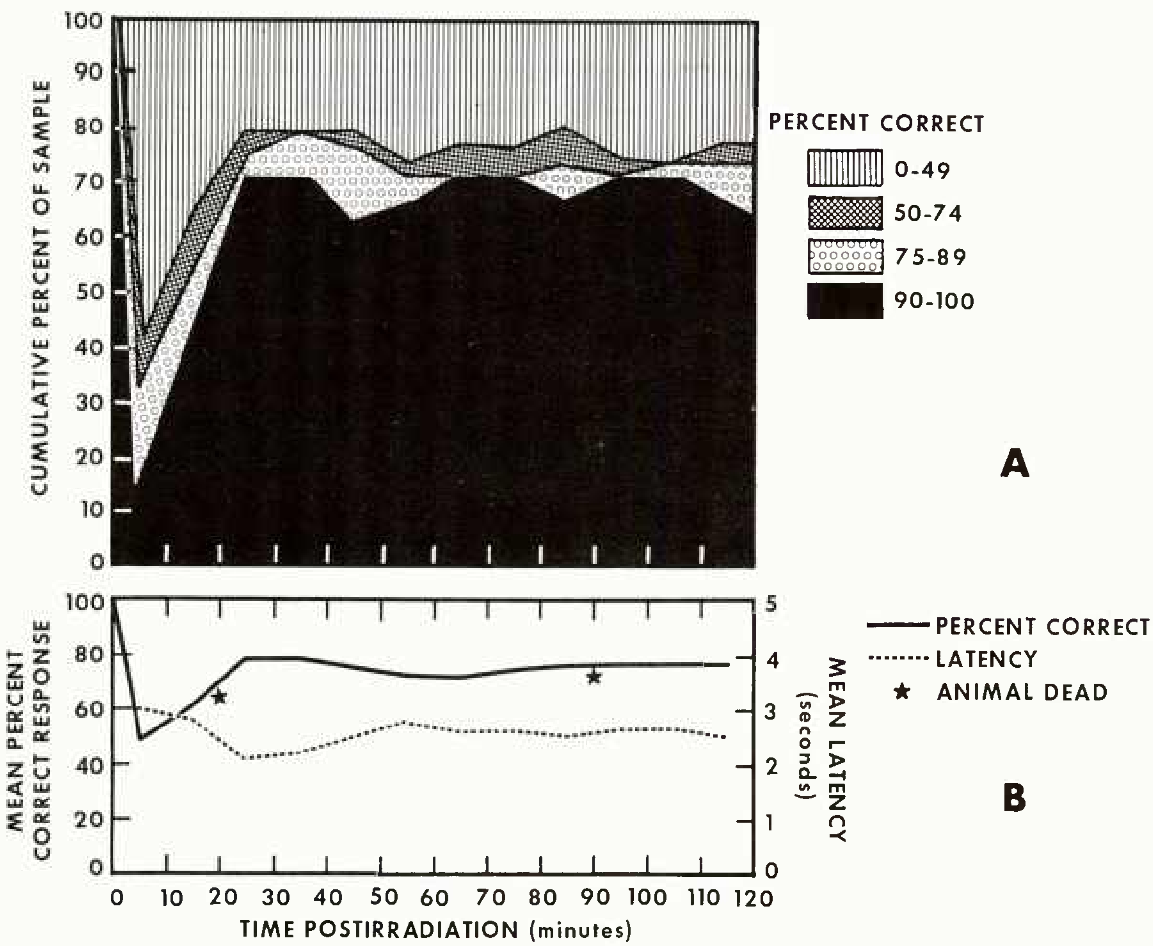

Figure 4. Behavioral data for animals (39) exposed to 2600 rads (midline tissue dose) of mixed gamma-neutron radiation

The first observable disruption of performance following radiation exposure occurred within the first 10 minutes postirradiation. At this time many of the animals appeared physically incapacitated; the severity of this incapacitation ranged from disorientation to coma.* During this time, other animals were able to perform the behavioral task but at a level significantly below base-line performance. Still other subjects continued to perform near their preirradiation level with no apparent behavioral deficit (see Table A-2).

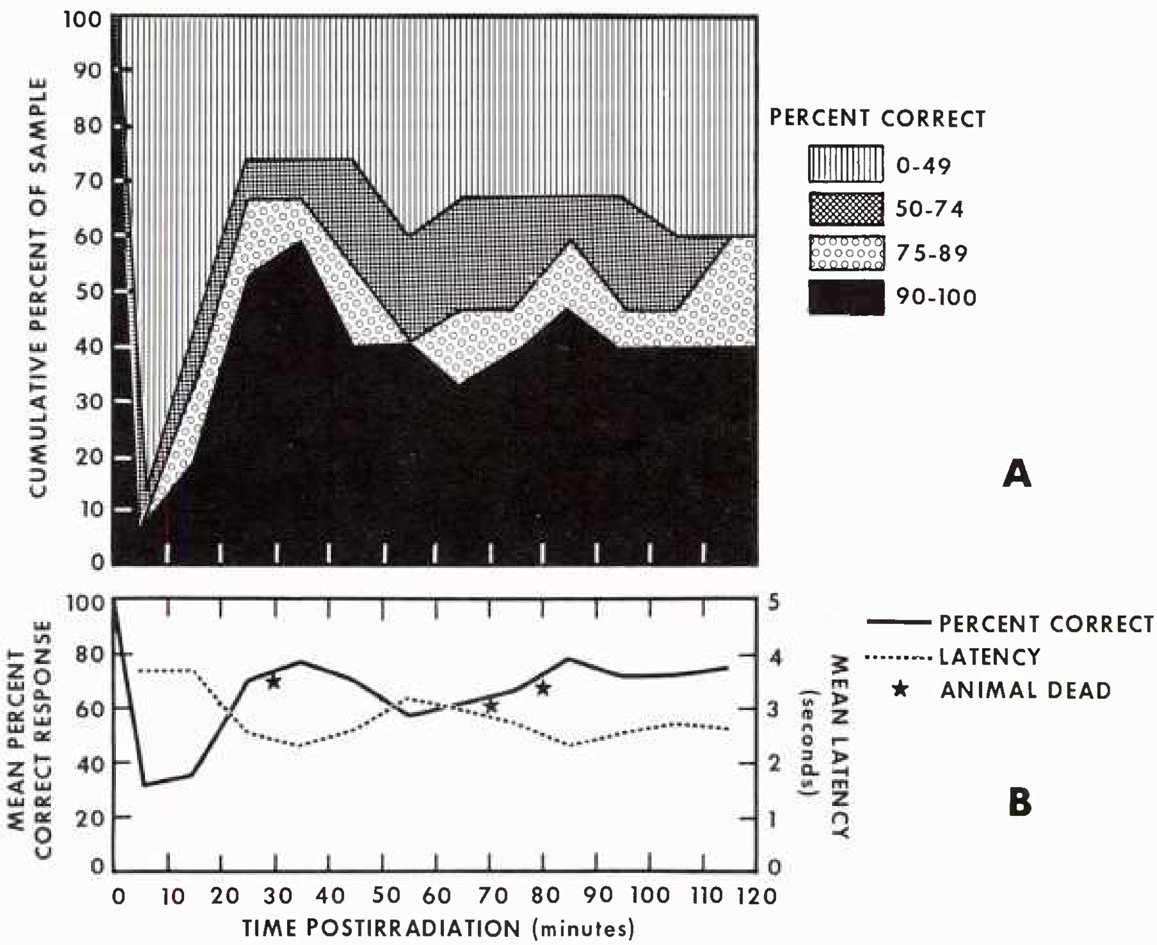

Figure 5. Behavioral data for animals (15) exposed to 4900 rads (midline tissue dose) of mixed gamma-neutron radiation

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* This first disruption of performance is generally referred to in the literature as the early transient incapacitation (ETI) or early performance decrement period

The graphs of mean correct responses and mean latency (Figures 2B - 5B) indicate that, following doses as high as 4900 rads, the performance of most subjects generally approached base-line levels following the initial decrement period. In some cases, performance during the recovery period equaled base-line levels of performance for both the accuracy and latency of response. The incidence and severity of the initial performance decrement and the degree of recovery appear to be dose dependent (Figure 8). The one apparent exception, the recovery level reached by the 8900-rad group (Figure 6B), is misleading because the performance of this group after 90 minutes

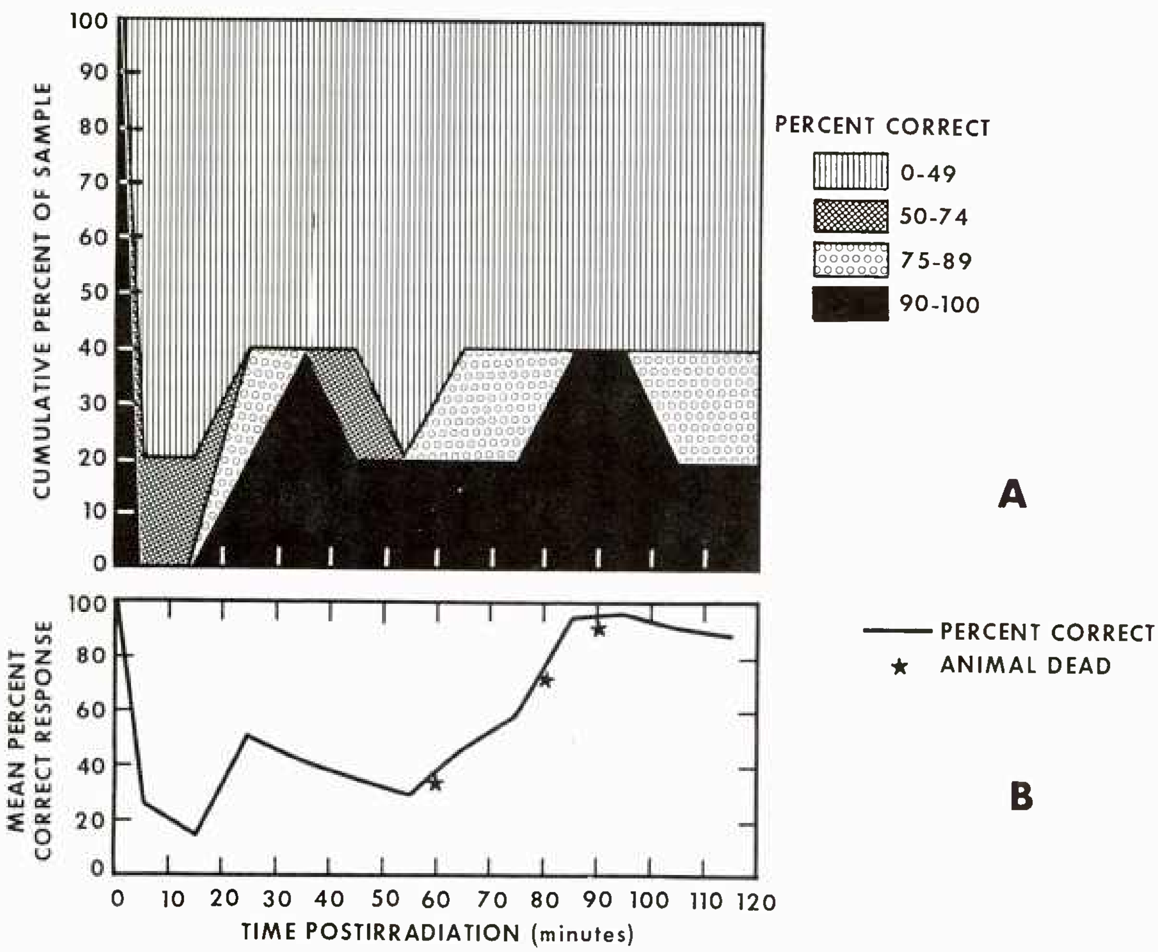

Figure 6. Behavioral data for animals (5) exposed to 8900 rads (midline tissue dose) of mixed gamma-neutron radiation. Latency data are not available.

postirradiation is limited to the mean percent correct of the two animals surviving beyond that point rather than the overall performance of the original sample.

The duration of the recovery period cannot be accurately assessed from these data because of the limited number of subjects which were tested until death. Available survival times for those animals exposed to doses of 1100, 4900, 8900, and 15,200 rads are listed in Table A-1.

In addition to the behavioral testing, each of the animals reported herein was visually monitored via closed circuit television for the first 2 hours postirradiation.

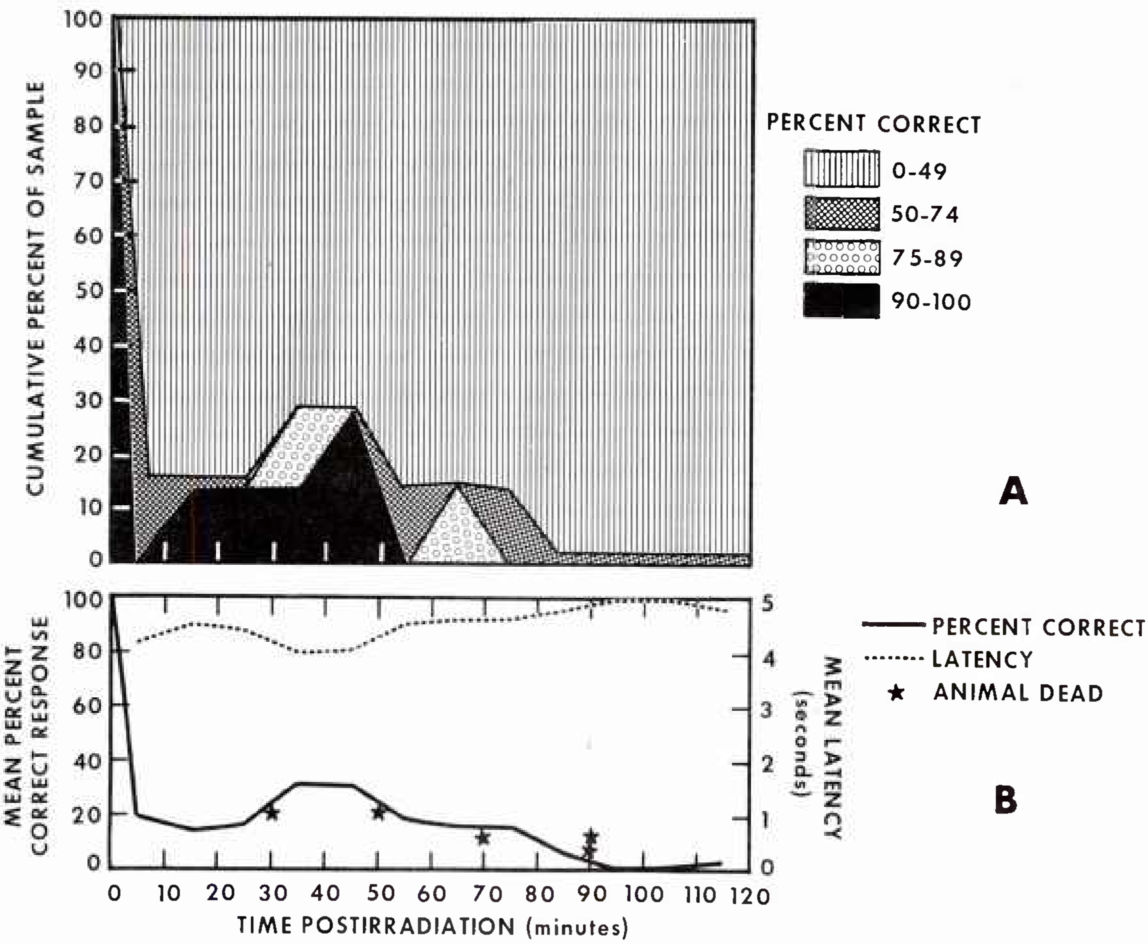

Figure 7. Behavioral data for animals (7) exposed to 15,200 rads (midline tissue dose) of mixed gamma-neutron radiation

Vomiting was the primary manifestation of radiation damage remotely observed during this period. Emesis (expulsion of vomitus) occurred in 30 percent* of the animals used in these studies and was most evident in the animals which were exposed to doses of 1700, 2600, and 8900 rads of radiation (see Table A-1). It should be noted, however, that the occurrence of vomiting may have been significantly influenced by the fact that all the animals used in this study were fasted for at least 17 hours prior to exposure.

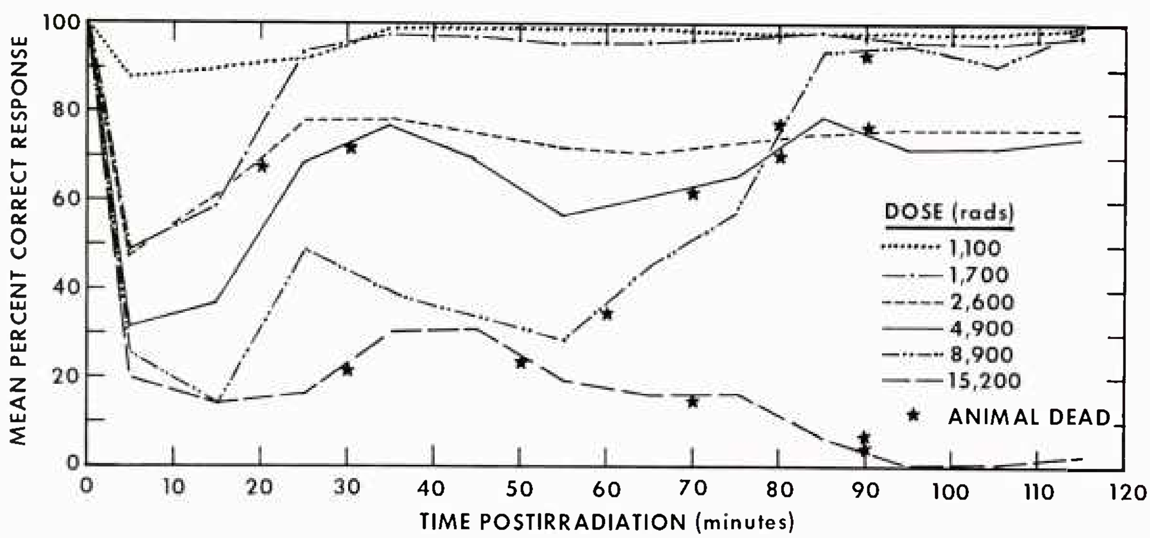

Figure 8. Mean percent correct response for all groups exposed to mixed gamma-neutron radiation

IV. DISCUSSION

The data reported herein indicate that both the incidence and severity of behavioral impairment following radiation in the supralethal range are dose dependent. A decrement in performance was noted with a dose of 1100 rads, the lowest dose studied

* Nausea and vomiting may have occurred in a greater number of the animals; however the monkeys' ability to retain vomitus in their cheek pouches could preclude detection via closed circuit television

to date at AFRRI. Other studies[2, 19, 22, 23] have indicated that a disruption in performance capability occurred following single dose exposures in the range of 1000 rads. When the School of Aerospace Medicine[3, 4] exposed monkeys to multiple 500-rad doses of radiation separated by 15-minute intervals, they reported no significant change in performance even when the cumulative dose reached 2500 rads. Therefore, it can be assumed that the minimum single dose required to significantly impair a subject's ability to accurately perform a relatively simple learned task is between 500 and 1000 rads.

The nature of the behavioral task appears to be a significant factor influencing postirradiation performance. In a collaborative study between AFRRI and the School of Aerospace Medicine,[6] the performance of irradiated animals trained to operate a primate equilibrium platform (PEP) was compared to the performance of animals with similar radiation exposure but required to perform the paired discrimination task described in this report. No significant differences were observed in the incidence and severity of early transient incapacitation. However, the level of recovery observed in the discrimination-trained animals 30 minutes postirradiation was not reached by the PEP-trained animals until 150 minutes after exposure.

Curran et al.[9] also reported that if physical activity was superimposed on a simple avoidance task, the animals' ability to perform was further diminished postirradiation. It would appear that this finding is simply a manifestation of the lethargy which is typical of the prodromal syndrome. However, requiring the animals to move a distance of approximately 3 feet did produce a significant decrease in observed performance levels.

A previous study[21] in which the animals were not required to perform a learned task postirradiation but rather to react in a defensive manner by reflexly avoiding a noxious stimulus lends additional credence to the significant influence of the behavioral task selected as a measure of postirradiation performance capability. One hundred and thirty-one animals were used in the previous study with single pulsed doses of gamma-neutron radiation ranging from 2500 to 80,000 rads, free-in-air. Using the simple escape from a noxious stimulus as a criterion, the investigators divided the postirradiation performance of the monkey into five distinct segments (Figure 9). Within minutes after exposure, the animals began to lose their ability to make an avoidance response (the 1st decline) which terminated in early transient incapacitation (ETI). During the ETI

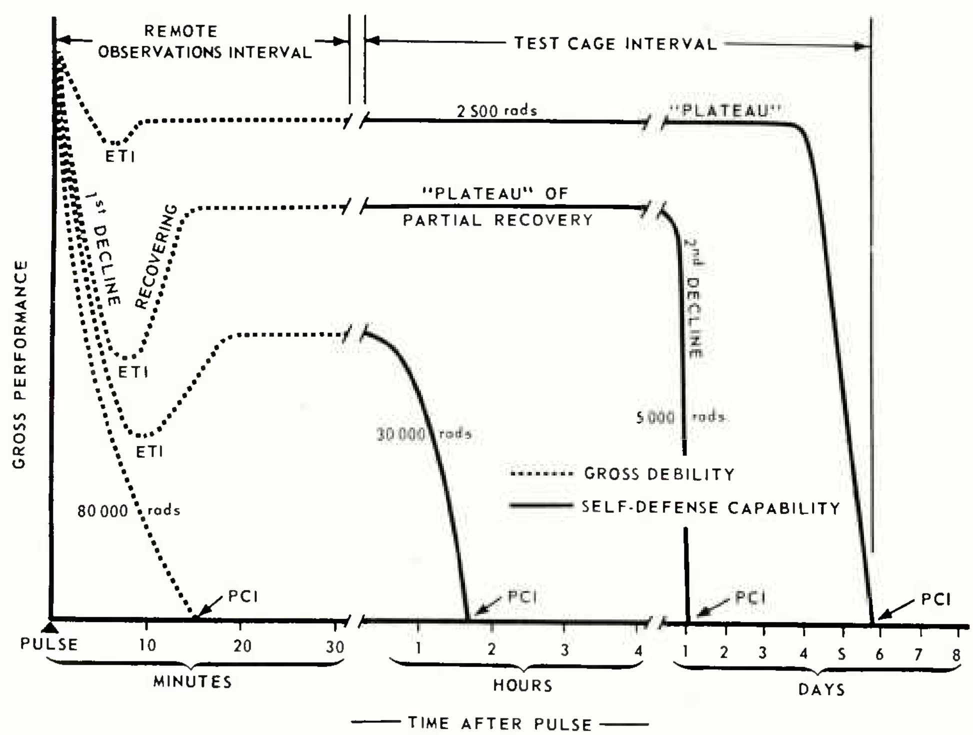

Figure 9. Schematic illustration of gross physiological debility and self-defense capability in the Macaca mulatta following exposure to pulsed reactor radiations (from AFRRI SR66-2[21])

period, the animals failed to respond to the stimuli. After 5 to 30 minutes in the ETI period, the subjects began to regain their ability to avoid the noxious stimulus (the recovery period). The degree of recovery appeared to be dosc dependent and generally stabilized ("plateau" of partial recovery) at a level of efficiency below that observed preirradiation. The duration of the recovery plateau also appeared to be dose dependent and terminated with a decline in performance ability (2nd decline) which resulted in permanent complete incapacitation (PCI). During the final phase (PCI), the animals failed to demonstrate any performance capability. PCI is terminated by the death of the animal.

Despite the basic descriptive accuracy of the Seigneur and Brennan[21] study of gross escape behavior postirradiation, it now appears that their projections of dose response relationships were conservative for behavioral tasks in general. For example, it was concluded that PCI is rarely produced in less than 1 hour at doses less than 30,000 rads and that a dose of 100,000 rads would be required to produce PCI within 30 seconds after exposure. The data reported here, from animals required to perform a learned task, indicate that the dose required to produce PCI within 1 hour postirradiation is approximately 20,000 rads, free-in-air. Although supporting data are limited, it would also appear that a dose of approximately 50,000 rads, free-in-air, would produce PCI for a simple learned task within the first 10 minutes postirradiation and possibly within the 30-second criterion used by Seigneur and Brennan. Based on these reductions in the projected dose levels required to produce PCI and the task differences reported by Brown et al.,[6] it is clear that the level of performance observed after irradiation is not only a function of the radiation parameters but also varies with the complexity of the task, sensitivity of the behavioral measures, and end points of interest.

In addition, recent studies have reported a greater degree of behavioral decrement following gamma ray exposure than was observed with neutron irradiation. For monkeys, neutrons were only 68 percent as effective for the production of early performance decrement as were gamma photons.[26] Additional evidence for the greater behavioral effects of gamma rays compared to neutrons can be obtained from the previously mentioned collaborative study between AFRRI and the School of Aerospace Medicine.[6] In that study, the performance of animals exposed to a mixed radiation spectrum high in neutrons was affected less than that of animals performing a similar task and exposed to a mixed radiation spectrum high in gamma rays. When one considers these limited data concerning the variation in behavioral response resulting from radiation difference, especially gamma-neutron ratio, there is a strong indication that the existing postirradiation performance data are relatively specific to the radiation source employed to produce that data. Unqualified generalization of performance effects to other radiation conditions would appear to be inappropriate.

It would appear that if further gains are to be made in the ability to generalize and predict the postirradiation performance capabilities of man from animal experimentation, future behavioral studies should be directed toward more specific behaviors. For example, studies concerning the effect of radiation on specific sensory and/or motor functions could be used in conjunction with military job analysis to predict the ability of troops to perform critical tasks postirradiation.

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APPENDIX A

Table A-1. Individual Animal Data

Animal #	Age (months)	Weight (kg)	Midline tissue dose (rads)	Time of emesis (minutes)	Survival (hours)
J-3	21	2.4	1129		214
W-25	21	2.4	1129		192
Fl-12	24	3.6	1105	41	191
Fl-31	18	3.2	1105		194
Fl-3	24	2.8	1058		173
Fl-10	24	3.2	1058		192
Fl-21	24	3.4	1023		166
Gl-52	24	3.4	1023		142
Gl-13	18	3.0	1116		210
Hl-29	28	3.2	1116		168
222	30	3.4	1790	56	*
230	30	3.4	1700		*
171	24	4.2	1700	7	*
240	18	3.5	1700	42	*
244	24	3.7	1700		*
218	24	2.9	1700		*
213	30	2.9	1700	34	*
226	30	2.7	1700	5	*
216	30	2.5	1800		*
227	30	3.6	1800		*
214	30	3.3	1700	66	*
217	30	3.6	1790		*
250	30	3.6	2700		*
304	18	3.1	2700		*
268	18	3.5	2700		*
2	29	4.0	2700		*
298	18	3.4	2630	56	*
14	30	3.7	2700		*
151	29	5.2	2550		*
254	18	3.9	2700		*
149	29	5.3	2550		*
203	28	4.3	2600	41	*
239	30	3.4	2700		*
296	24	3.7	2630		*
245	15	3.5	2700		*
228	30	3.3	2850		*
B-73	24	2.7	2700		*
B-23	18	3.2	2650	35	*
113	30	4.4	2750	63	*
B-30	18	2.8	2750	44	*
803	42	4.4	2350	54	*
63	26	4.2	2600	20	*
27	39	3.6	2650		*
10	51	3.7	2750		*

* Survival time not obtained

Animal #	Age (months)	Weight (kg)	Midline tissue dose (rads)	Time of emesis (minutes)	Survival (hours)
20	50	3.8	2700		*
4	41	4.2	2700	14	*
25	47	3.6	2700		*
31	49	3.8	2700		*
828	33	3.1	2600	49	*
59	26	3.4	2600	30	*
176	18	3.7	2600		*
164	18	4.1	2500		*
130	18	2.7	2500		*
178	18	4.5	2600	42	*
B-11	18	2.8	2600		*
B-17	36	3.2	2650	24	*
B-57	24	3.2	2700	4	*
C-3	18	3.2	2600		3.0
817	19	2.9	2600		3.3
818	31	2.9	2650	33	*
11	32	4.1	2700		1.6
C-27	18	3.6	5200		1.9
1	18	3.5	4900		1.3
33	18	3.8	5200		0.4
291	24	3.3	5100	44	34.0
12	36	3.6	5100		16.0
9	24	3.4	4900		18.0
48	18	3.5	5200		14.0
B-27	30	3.6	5000		42.0
C-12	24	3.3	5000		28.0
C-33	42	4.0	5200		28.0
768	30	3.4	4500	20	20.8
781	36	3.6	4500		79.0
785	30	3.2	4500		27.0
780	36	3.8	4700		151.0
778	30	3.5	4800		1.1
748	†	†	8700	31	4.2
758	†	†	8900		.9
771	†	†	8900		1.2
759	†	†	8800	42	24.0
776	†	†	8700		1.1
202	28	3.4	15200		3.3
179	32	4.7	15300		2.3
172	31	4.1	15200		1.3
204	30	4.0	15000		1.3
183	30	3.7	15300		1.2
181	30	4.7	15400	9	.8
182	31	4.1	15400		.5

† Not available

Table A-2. Postirradiation Performance given as Percent Correct Response for Individual Animals

Animal #	Exposure group (rads)	Time postirradiation (minutes)											
		10	20	30	40	50	60	70	80	90	100	110	120
J-3	1100	88	98	100	98	98	98	100	100	100	98	94	100
W-25	1100	86	100	100	100	100	92	96	100	100	100	100	98
Fl-12	1100	94	100	100	100	100	100	98	100	98	98	98	100
Fl-31	1100	98	100	100	100	96	100	100	100	100	96	100	98
Fl-3	1100	98	98	100	98	100	100	100	100	100	98	100	96
Fl-10	1100	100	100	100	98	100	98	98	100	100	100	94	95
Fl-21	1100	30	6	24	100	100	100	100	96	98	100	100	100
Gl-52	1100	100	100	100	100	100	98	94	80	86	92	94	100
Gl-13	1100	92	100	100	100	100	100	100	100	100	100	100	100
Hl-29	1100	96	100	98	100	98	100	100	100	100	100	98	100
222	1700	22	90	98	100	98	92	100	100	100	100	74	80
230	1700	80	78	100	100	98	98	98	100	100	100	100	100
171	1700	16	0	44	80	92	94	80	98	86	94	98	100
240	1700	96	86	96	98	92	84	94	96	100	100	100	100
244	1700	98	100	100	98	100	94	98	96	100	100	100	100
218	1700	40	100	100	100	96	98	100	100	94	82	100	92
213	1700	48	62	100	100	98	100	100	96	100	100	100	100
226	1700	66	84	100	100	94	100	98	100	100	98	98	98
216	1700	22	0	94	100	100	100	100	100	100	100	100	100
227	1700	32	22	100	98	100	100	100	100	100	100	100	100
214	1700	32	0	100	100	100	98	94	88	100	94	88	94
217	1700	36	80	100	100	98	96	84	92	92	98	98	100
250	2600	26	14	96	92	92	94	96	94	98	98	94	98
304	2600	40	98	100	100	100	98	98	98	100	100	90	98
268	2600	88	100	100	100	94	94	98	98	100	100	100	100
2	2600	32	0	0	0	0	0	0	0	0	0	0	0
298	2600	78	98	100	100	100	90	100	100	100	98	96	98
14	2600	98	100	94	96	94	90	94	96	76	94	94	98
151	2600	12	44	100	100	96	94	94	100	98	100	92	92
254	2600	16	12	96	98	86	74	70	62	92	94	96	88
149	2600	62	58	100	98	82	82	98	96	98	94	98	94
203	2600	32	14	72	4	14	2	60	70	74	62	48	66
239	2600	58	78	90	84	66	28	36	32	54	42	80	76
296	2600	98	98	100	100	100	96	98	96	100	100	100	100
245	2600	12	0	0	0	0	0	0	0	0	0	0	0
228	2600	24	96	98	100	82	38	6	0	10	0	0	0
B-73	2600	90	100	100	100	96	94	98	100	98	100	100	98
B-23	2600	54	96	100	98	94	92	92	98	98	100	98	98
113	2600	84	94	94	94	100	98	96	98	96	96	92	100
B-30	2600	46	76	100	96	94	86	100	98	100	98	100	100
803	2600	24	96	100	98	98	96	100	96	100	100	98	98
63	2600	90	100	96	100	96	98	100	98	100	98	100	100
27	2600	24	0	88	98	88	98	98	100	100	100	100	100
10	2600	46	100	100	100	98	90	96	94	92	96	98	98

Table A-2 (continued)

Animal #	Exposure group (rads)	Time postirradiation (minutes)											
		10	20	30	40	50	60	70	80	90	100	110	120
20	2600	72	82	96	98	100	98	96	96	98	92	100	96
4	2600	40	62	98	98	88	90	90	94	98	100	98	100
25	2600	22	2	62	78	90	94	92	90	98	100	100	96
31	2600	18	22	98	100	92	96	96	94	100	100	98	96
828	2600	78	100	100	100	94	100	98	100	78	42	10	4
59	2600	84	98	109	98	96	92	96	98	98	98	98	96
176	2600	18	80	94	100	98	100	100	100	100	96	100	98
164	2600	20	58	94	100	100	100	100	100	100	100	100	100
130	2600	18	0	0	0	0	0	0	0	0	0	0	0
178	2600	98	100	100	100	96	100	100	100	100	100	100	100
B-11	2600	34	0	96	100	100	100	100	98	100	100	100	98
B-17	2600	76	98	98	100	100	94	100	100	98	98	100	100
B-57	2600	98	100	100	98	98	92	94	98	100	100	100	100
C-3	2600	10	0	0	0	0	0	0	0	0	0	0	0
817	2600	24	78	0	0	0	0	0	0	0	0	0	0
818	2600	6	0	0	0	0	0	0	0	0	0	0	0
11	2600	16	0	0	0	0	0	0	0	0	--	--	--
C-27	4900	20	0	92	98	82	4	20	0	4	0	0	--
1	4900	10	0	0	0	0	0	0	--	--	--	--	--
33	4900	22	0	--	--	--	--	--	--	--	--	--	--
291	4900	14	22	92	96	40	0	56	72	86	92	94	92
12	4900	40	76	98	100	80	52	88	98	100	100	100	100
9	4900	10	0	36	98	96	98	98	94	98	98	100	98
48	4900	18	0	78	100	100	100	100	100	100	100	100	100
B-27	4900	92	94	100	100	98	100	98	100	100	98	98	90
C-12	4900	18	0	86	100	98	98	64	52	100	74	6	38
C-33	4900	22	74	100	100	98	98	96	100	100	88	88	84
768	4900	36	0	2	4	94	98	98	98	98	96	98	98
781	4900	18	8	94	88	58	24	0	0	0	2	74	80
785	4900	36	96	100	70	56	54	62	66	74	66	64	78
780	4900	64	82	96	90	66	66	80	80	82	54	44	32
778	4900	48	96	64	38	0	0	--	--	--	--	--	--
748	8900	64	16	82	98	98	100	100	98	98	100	88	84
758	8900	10	0	0	0	0	--	--	--	--	--	--	--
771	8900	14	0	0	0	0	0	0	--	--	--	--	--
759	8900	28	54	96	98	70	10	80	76	90	92	94	92
776	8900	12	0	0	0	0	0	--	--	--	--	--	--
202	15,200	4	0	0	84	92	24	2	0	0	0	0	0
179	15,200	66	94	98	98	92	72	76	62	12	0	0	4
172	15,200	22	2	4	0	0	0	0	--	--	--	--	--
204	15,200	12	0	0	0	0	0	0	--	--	--	--	--
183	15,200	10	0	8	0	0	0	0	--	--	--	--	--
181	15,200	18	0	2	0	--	--	--	--	--	--	--	--
182	15,200	10	0	0	--	--	--	--	--	--	--	--	--

Table A-3. Postirradiation Performance given as Latency of Response in Seconds for Individual Animals

Animal #	Exposure group (rads)	Time postirradiation (minutes)											
		10	20	30	40	50	60	70	80	90	100	110	120
J-3	1100	1.5	1.2	1.7	2.2	2.2	2.4	1.5	1.6	1.5	2.1	1.6	1.4
W-25	1100	1.6	.8	.9	.9	1.4	2.0	1.2	1.2	1.1	1.4	1.5	1.7
Fl-12	1100	1.2	.9	1.0	.9	1.0	1.0	.9	.8	1.0	.9	1.0	1.0
Fl-31	1100	1.0	.9	1.0	1.3	2.1	1.5	1.3	1.2	1.3	1.8	1.8	2.0
Fl-3	1100	.7	1.0	.9	.8	.8	.8	.9	1.0	1.2	1.8	1.6	1.9
Fl-10	1100	.9	1.0	1.2	1.3	1.2	1.2	1.2	1.2	1.3	1.4	2.0	2.1
Fl-21	1100	3.8	4.9	4.1	1.0	1.1	1.4	1.8	2.1	2.1	1.7	1.8	2.0
Gl-52	1100	.7	.8	.9	1.1	1.1	1.4	1.9	2.2	2.1	1.7	1.5	1.2
Gl-13	1100	.9	.9	1.0	1.1	1.0	1.1	1.2	1.2	1.2	1.2	1.2	1.4
Hl-29	1100	1.0	1.0	.9	.9	.9	.9	1.0	1.0	1.0	1.2	1.0	1.2
222	1700	3.9	2.0	1.3	1.2	1.7	1.3	1.3	1.6	1.8	1.8	3.1	2.8
230	1700	2.5	2.5	1.8	2.2	2.4	2.8	2.4	2.4	2.6	2.4	2.1	2.0
171	1700	4.6	5.0	3.4	1.6	2.0	2.1	2.6	1.7	1.5	1.5	1.8	1.9
240	1700	2.0	3.0	1.8	2.2	2.1	2.4	1.7	1.9	1.5	1.8	1.8	1.8
244	1700	1.1	1.2	1.2	1.4	1.6	2.0	2.1	1.9	1.6	1.6	1.7	1.9
218	1700	3.3	1.4	1.6	1.4	1.1	1.1	1.3	1.7	1.6	1.8	2.2	1.8
213	1700	3.6	2.8	1.4	1.7	1.9	1.7	2.1	1.9	1.8	2.0	2.1	2.0
226	1700	3.0	1.4	1.6	1.6	1.6	1.6	1.5	1.5	1.6	1.6	1.4	1.5
216	1700	4.1	5.0	1.5	1.0	1.1	1.4	1.1	1.2	1.1	1.2	1.0	1.2
227	1700	3.9	4.7	1.1	1.3	1.4	2.1	1.4	1.4	1.5	1.9	2.4	2.6
214	1700	3.7	5.0	1.8	1.7	2.0	1.9	2.6	1.9	1.7	2.8	2.5	2.1
217	1700	4.6	1.9	1.4	1.6	2.0	2.3	2.8	2.6	2.7	2.6	2.7	2.4
250	2600	4.0	4.3	1.4	1.1	1.2	1.8	1.4	1.4	1.3	1.3	1.2	1.1
304	2600	3.5	2.0	1.3	1.4	1.5	1.6	1.9	2.1	1.9	1.7	2.7	2.2
268	2600	1.7	1.4	1.3	1.5	2.0	2.0	1.8	1.9	1.7	1.8	1.6	1.9
2	2600	3.9	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	4.9
298	2600	2.1	1.8	1.3	1.3	1.7	1.8	2.0	2.0	2.2	2.8	2.4	1.6
14	2600	1.7	1.6	1.9	1.6	2.3	2.2	2.0	1.7	1.6	1.3	1.2	1.3
151	2600	4.3	3.4	1.0	1.3	1.3	2.1	1.5	1.4	1.3	1.5	1.9	1.4
254	2600	3.5	4.4	1.9	2.1	2.5	2.8	3.1	3.0	2.3	2.4	2.3	1.7
149	2600	2.6	2.8	1.0	1.6	2.0	2.7	1.9	1.8	1.9	2.4	1.9	2.2
203	2600	4.2	3.7	2.7	3.8	3.9	5.0	3.2	3.3	3.0	3.6	4.2	3.5
239	2600	2.9	2.1	2.7	3.4	3.4	4.1	4.1	3.8	3.9	3.7	2.8	2.8
296	2600	1.1	1.0	1.0	1.2	1.4	2.7	2.3	2.7	2.2	2.1	2.0	2.4
245	2600	4.5	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
228	2600	4.2	1.9	1.8	1.9	3.1	3.9	4.8	5.0	4.7	5.0	5.0	5.0
B-73	2600	1.7	1.3	1.1	1.3	2.1	2.1	2.2	1.9	1.9	2.0	1.7	1.9
B-23	2600	2.9	1.3	1.2	1.5	1.9	1.9	1.8	1.7	1.5	1.3	1.1	1.1
113	2600	1.3	1.5	1.2	1.2	1.2	1.6	1.7	1.6	1.6	1.7	2.0	1.9
B-30	2600	3.5	2.2	1.5	2.4	2.2	2.9	1.6	1.8	1.6	2.2	1.8	2.1
803	2600	4.3	2.0	1.8	2.1	2.0	1.7	2.1	2.3	1.8	2.3	2.5	2.6
63	2600	.8	1.1	1.0	.9	1.5	1.6	1.3	1.3	1.2	1.4	1.4	1.3
27	2600	4.1	5.0	2.7	2.7	2.0	1.9	2.1	2.2	2.1	2.2	2.2	2.1
10	2600	3.0	1.2	1.4	1.6	1.8	1.9	1.7	1.8	2.0	1.9	2.0	2.0

Table A-3 (continued)

Animal #	Exposure group (rads)	Time postirradiation (minutes)											
		10	20	30	40	50	60	70	80	90	100	110	120
20	2600	1.8	1.5	1.2	1.5	1.9	1.8	2.0	2.1	2.3	2.6	2.4	2.2
4	2600	3.4	2.6	1.1	1.2	1.7	2.0	1.9	1.8	1.5	1.7	2.2	2.0
25	2600	4.4	5.0	3.0	2.3	1.5	1.7	1.8	1.8	1.5	1.4	1.7	1.7
31	2600	4.2	4.6	2.1	2.1	2.2	2.0	2.0	1.7	2.0	2.1	2.0	1.8
828	2600	1.4	.9	1.2	1.3	2.0	1.7	1.3	1.8	2.6	4.5	4.9	5.0
59	2600	1.8	1.0	1.0	1.1	2.1	2.0	2.4	2.3	2.8	3.1	3.0	2.7
176	2600	4.3	1.7	1.3	1.2	1.1	1.3	1.5	1.4	1.7	2.0	2.0	1.9
164	2600	4.2	3.2	1.1	1.1	1.2	1.1	1.1	1.2	1.5	1.3	1.7	1.7
130	2600	4.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
178	2600	1.0	1.0	.9	1.1	1.1	1.3	1.6	1.8	1.5	1.7	1.5	1.5
B-11	2600	3.7	5.0	1.5	1.1	1.1	1.1	1.7	1.8	.9	1.1	1.1	1.1
B-17	2600	2.5	1.5	1.4	1.4	2.0	2.8	1.8	2.0	1.7	1.6	1.5	1.6
B-57	2600	2.0	1.4	1.5	1.2	1.8	2.4	2.1	1.8	1.6	1.5	1.5	1.3
C-3	2600	4.3	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
817	2600	4.0	2.2	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
818	2600	4.8	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
11	2600	4.4	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	--	--	--
C-27	4900	4.2	5.0	2.2	1.8	2.3	4.7	4.4	5.0	4.9	5.0	5.0	--
1	4900	4.6	5.0	5.0	5.0	5.0	5.0	5.0	--	--	--	--	--
33	4900	3.5	5.0	--	--	--	--	--	--	--	--	--	--
291	4900	4.4	4.0	.7	.8	3.0	5.0	2.0	1.2	.9	.8	.8	1.0
12	4900	3.4	2.2	1.1	1.2	2.1	2.7	1.9	1.4	1.2	1.3	1.3	1.3
9	4900	4.4	5.0	4.0	2.0	2.0	1.8	1.8	1.9	1.6	1.7	1.9	1.7
48	4900	4.4	5.0	2.2	1.4	1.4	1.6	1.5	1.5	1.6	1.5	1.6	1.6
B-27	4900	1.2	1.1	1.4	1.6	1.6	1.9	2.0	1.8	1.7	1.7	1.8	1.9
C-12	4900	4.3	5.0	1.9	1.7	2.0	1.9	3.0	3.5	1.7	2.9	4.9	4.2
C-33	4900	4.2	2.3	1.2	1.2	1.7	2.0	1.3	1.6	1.0	2.3	2.4	2.5
768	4900	3.5	5.0	5.0	5.0	1.7	2.0	3.8	1.2	2.4	2.1	1.7	1.8
781	4900	4.5	5.0	2.4	2.7	3.2	4.6	5.0	5.0	5.0	5.0	2.9	2.9
785	4900	3.5	2.0	1.5	2.2	2.5	2.8	2.4	2.9	2.6	2.9	3.4	2.8
780	4900	2.3	2.3	2.2	2.3	3.1	3.1	2.9	3.2	3.3	3.4	4.1	4.4
778	4900	3.3	2.1	3.1	3.5	4.9	5.0	--	--	--	--	--	--
	8900*												
202	15,200	4.8	5.0	5.0	1.9	2.2	4.4	4.9	5.0	5.0	5.0	5.0	5.0
179	15,200	2.5	1.4	1.6	2.0	2.1	3.2	3.0	3.4	4.6	5.0	5.0	4.6
172	15,200	4.1	5.0	4.8	5.0	5.0	5.0	5.0	--	--	--	--	--
204	15,200	4.4	5.0	5.0	4.9	5.0	5.0	5.0	--	--	--	--	--
183	15,200	4.6	5.0	4.8	5.0	5.0	5.0	5.0	--	--	--	--	--
181	15,200	4.3	5.0	4.9	5.0	--	--	--	--	--	--	--	--
182	15,200	4.6	5.0	5.0	--	--	--	--	--	--	--	--	--

* Latencies not available

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13. ABSTRACT

Eighty-eight monkeys (Macaca mulatta) were trained to perform a shock motivated visual discrimination task and were exposed to a single supralethal dose of pulsed gamma-neutron radiation. The postirradiation performance of these animals is presented in a manner which facilitates group comparisons of performance following doses of approximately 1100, 1700, 2600, 4900, 8900 or 15,200 rads. At these dose levels, group performance declined within minutes after exposure. For some subjects, the decline was so severe that the animals appeared comatose. The frequency with which a behavioral decrement was observed and the severity of the initial decrement appeared to be dose dependent. After the initial decrement, most animals at least partially regained their ability to perform the discrimination task. Performance was generally maintained at recovery levels until shortly before death. Factors which appeared capable of modifying observed postirradiation behavior include the gamma-neutron ratio of the radiation source and the nature of the behavioral task employed.

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